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PREPRINT

RESULTS OF PRIM GYROSCOPE TESTING

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RESULTS OF PRIM GYROSCOPE TESTING

by

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155mm, XM785 Nuclear Projectile
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Introduction

The recently completed gyroscope experiments were a joint effort by BRL, LLNL, and SNLA. The test apparatus configuration was agreed upon by the three laboratories. LLNL produced the hardware and instrumentation. BRL supplied the flexural pivots, drive couplings and mounting stand. The experiments were conducted by LLNL at the BRL facility. All three laboratories reviewed the data.

The tests were designed so that motions of the gyroscope and the Partially Restrained Internal Member (PRIM) could be measured at different conditions of spin and PRIM clearance gaps. Two types of PRIM drive were tested. A round shaft configuration was used to test theory. An octagon drive was used to simulate the XM785 design.

Apparatus

Figure 1 details the gyroscope assembly while Figure 2 shows the motion sensing transducers. The gyroscope pivot angle sensors detect the tilting motion of the gyroscope while the non-contacting-displacement sensors measure the radial motion of the PRIM rotor with respect to the gyroscope spin axis. PRIM spin is measured with an external stroboscopic tachometer.

Data Reduction

Data is recorded as analog signals on magnetic tape. It is digitized before numerical reduction is done. After digitization the data is combined and manipulated to show the parameters of interest. These parameters are:

1. PRIM cant angle (γ) with respect to the gyroscope spin axis.

2. PRIM phase angle (Φ_γ) with respect to the tilt plane of the gyroscope.

3. PRIM cg eccentricity (ε) with respect to the gyroscope spin axis.

4. PRIM eccentricity phase angle (Φ_ε) with respect to the tilt plane of the gyroscope.

Figure 3 shows how to obtain the position of the gyroscope tilt plane from the pivot sensor data while Figure 4 shows how the four parameters of interest are calculated from PRIM rotor displacement data and tilt plane position angle.

Raw Data

In Figure 5 a channel of raw data is depicted. There are three stages of PRIM motion indicated. They are the initiation stage, the transition stage and finally the developed stage.

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Reduced Data

The reduced data in the following figures are from the developed stage of motion. Figure 6 is data from a round shaft experiment while Figure 7 shows data from an octagon drive shaft test. Notice the periodicity of the data. This is not predicted by the present theory and therefore it is not easy to translate the effects of these types of motion on projectile flight. The round shaft gives greater excursion in cant angle than the octagon shaft. The octagon drive produces greater eccentricity than the round shaft.

Evaluations

W. D'Amico, of BRL, has evaluated the gyroscope test data and has applied the results of these tests to Murphy's theory by filtering out all but the in phase components of motion. His analysis indicates that PRIM effects are probably small in the XM785 and that the octagon drive is beneficial in reducing the PRIM effect.

A. E. Hodapp, of SNLA, has looked at the possibility that the average PRIM axis is somewhat displaced from the axis of the XM785 projectile. The centrifugal force created by this offset overcomes the tendency for the PRIM to cant thus reducing PRIM flight problems. Hodapp estimates small to non-existent effects to XM785 performance. He believes, also, that the octagon drive is beneficial.

T. O. Morgan, of LLNL, is evaluating the test results by observing the data fit to his new equations which consider the PRIM as a gyroscope-within-a-gyroscope. Although incomplete at this time, Morgan's hypothesis predicts some of the periodic motion seen in the gyroscope experiments. He also estimates that there will be little to no effect of PRIM motion on XM785 flight performance. Morgan also endorses the beneficial effect of having an octagon drive.

Conclusions

Because the gyroscope tests show more dynamic PRIM motion than expected, it is difficult to make an immediate, definitive conclusion other than "we expect that the XM785 PRIM will have little effect on flight characteristics." We also concluded that the octagon drive of the XM785 PRIM is helpful in reducing the cant angle.

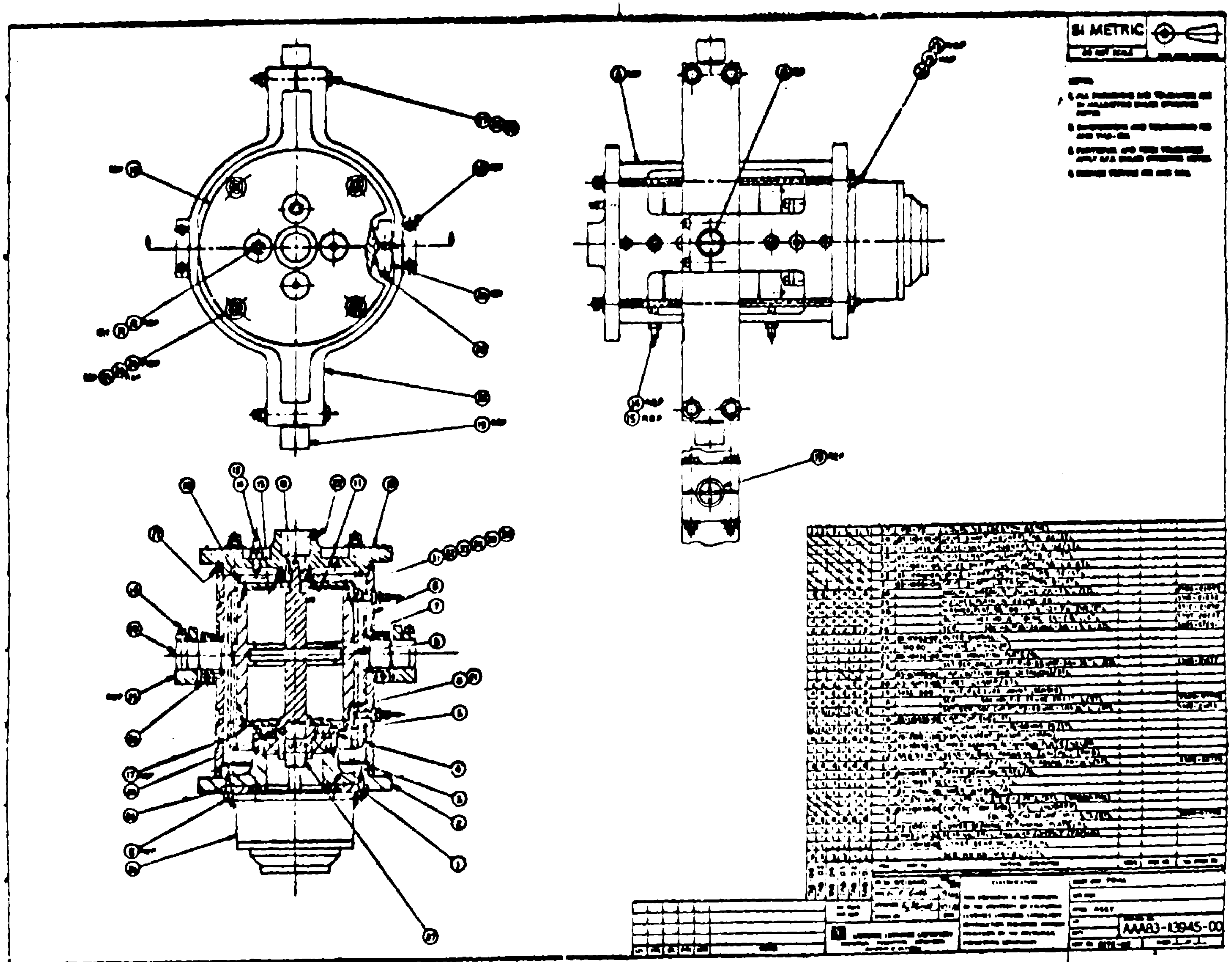


Figure 1 - Assembly drawing of PRIM gyroscope test apparatus

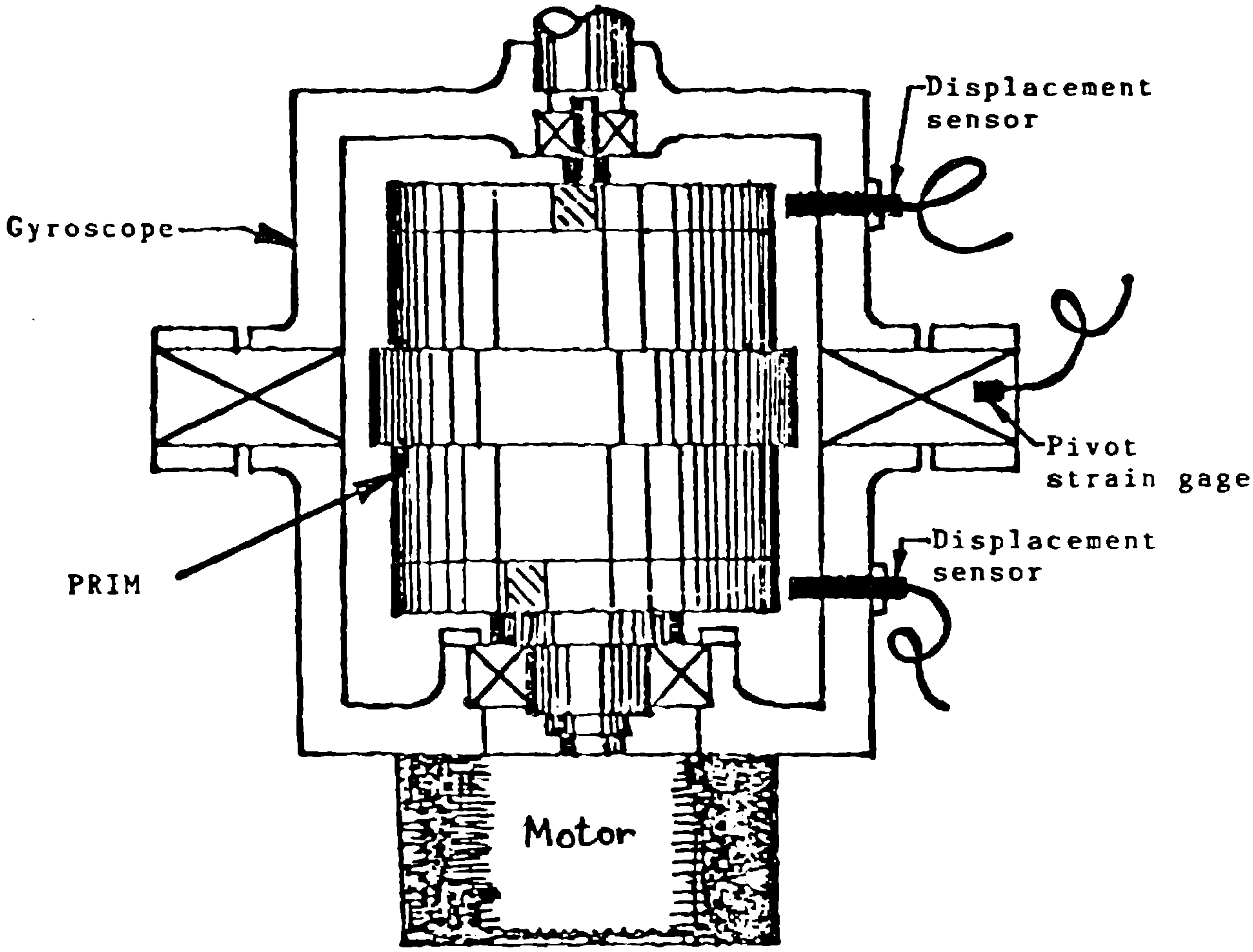
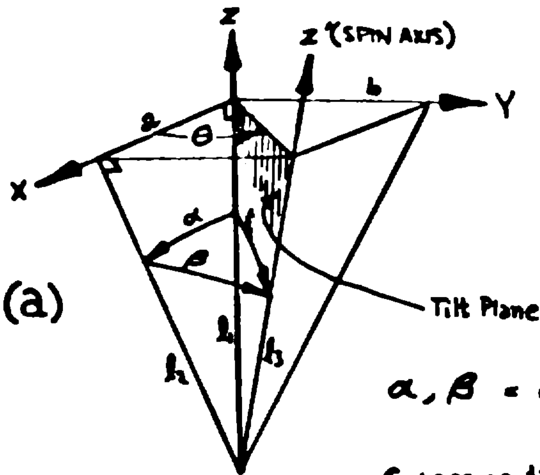


Figure 2 - Diagram showing sensors.

(a)

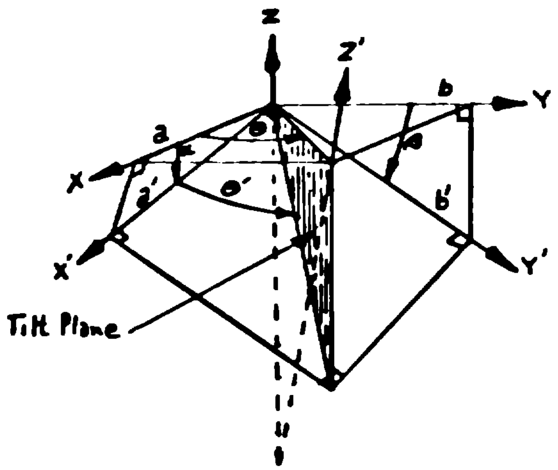


α, β = orthogonal gyroscope pivot data

Gyroscope tilt (ϕ) and tilt plane angle (θ) - Earth fixed reference (x, y, z)

$$l_2 = l_1/\cos\alpha$$
$$a = l_1 \tan\alpha$$
$$l_3 = l_2/\cos\beta = l_1/(\cos\alpha \cos\beta)$$
$$\phi = \cos^{-1}[\cos\alpha \cdot \cos\beta]$$
$$b = l_2 \tan\beta = l_1 \tan\beta/\cos\alpha$$
$$\theta = \tan^{-1}[b/a] = \tan^{-1}[\tan\beta/\sin\alpha]$$

(b)

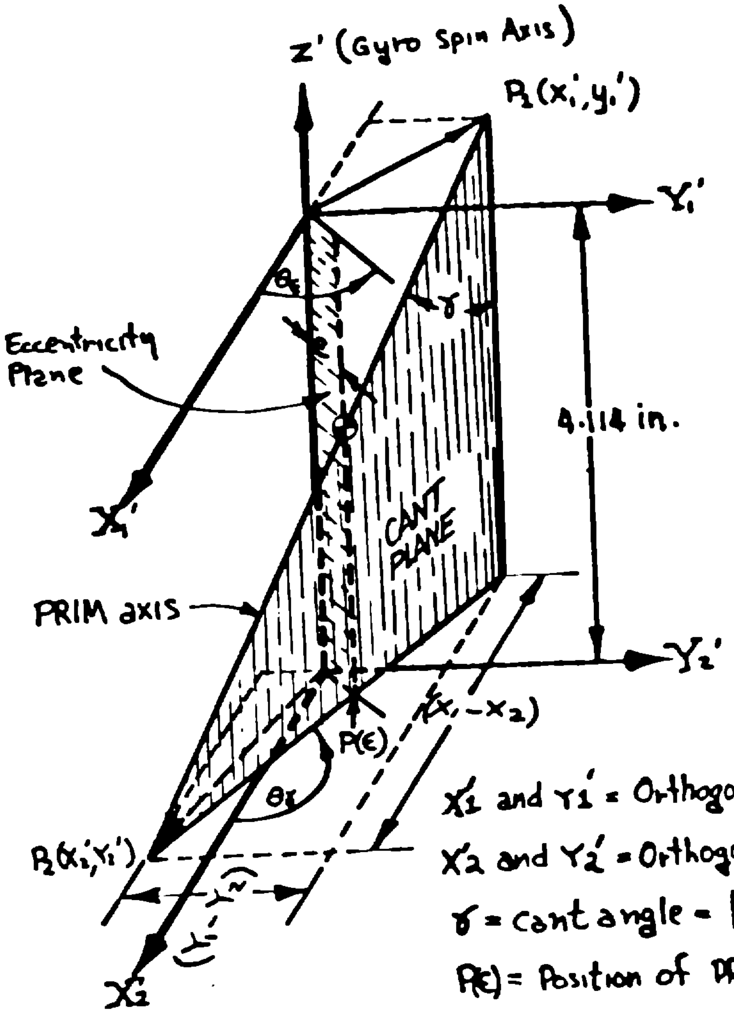


Gyroscope tilt plane angle (θ') - Gyro fixed reference (x', y', z')

$$a' = a/\cos\alpha = l_1 \tan\alpha/\cos\alpha$$
$$b' = b/\cos\beta = l_1 \tan\beta/(\cos\alpha \cos\beta)$$
$$\theta' = \tan^{-1}[b'/a'] = \tan^{-1}[\tan\beta/(\tan\alpha \cos\beta)]$$

(with respect to gyro x' axis)

Figure 3 - Deriving gyroscope position from pivot angle data α and β.



X_1' and Y_1' = Orthogonal PRIM displacement data - Top

X_2' and Y_2' = Orthogonal PRIM displacement data - Bottom

γ = cant angle = $[(X_1' - X_2')^2 + (Y_1' - Y_2')^2]^{1/2} / 4.114$ (small angle)

$P(\epsilon)$ = Position of PRIM cg : $X_\epsilon' = X_2' + R[X_1' - X_2']$
$Y_\epsilon' = Y_2' + R[Y_1' - Y_2]$

where: R = ratio of distance to the cg, from the bottom of the PRIM, to the length of the PRIM

ϵ = Eccentric offset of the PRIM's cg from the gyro's spin axis = $\sqrt{X_\epsilon^2 + Y_\epsilon^2}$

θ_γ' = cant plane angle with respect to gyro X' axis
$= \tan^{-1}(Y_1' - Y_2') / (X_1' - Y_2')$

θ_ϵ' = Eccentricity plane angle = $\tan^{-1}(Y_\epsilon' / X_\epsilon')$

ϕ_γ = Cant phase angle = $\theta_\gamma' - \theta'$

ϕ_ϵ = Eccentricity phase angle = $\theta_\epsilon' - \theta'$
where: θ' is the gyro-fixed-tilt-plane angle (Figure 3)

Figure 4 - Deriving γ, ϵ, Φ_γ and Φ_ϵ from PRIM motion data (x'&y') and gyroscope position (θ').

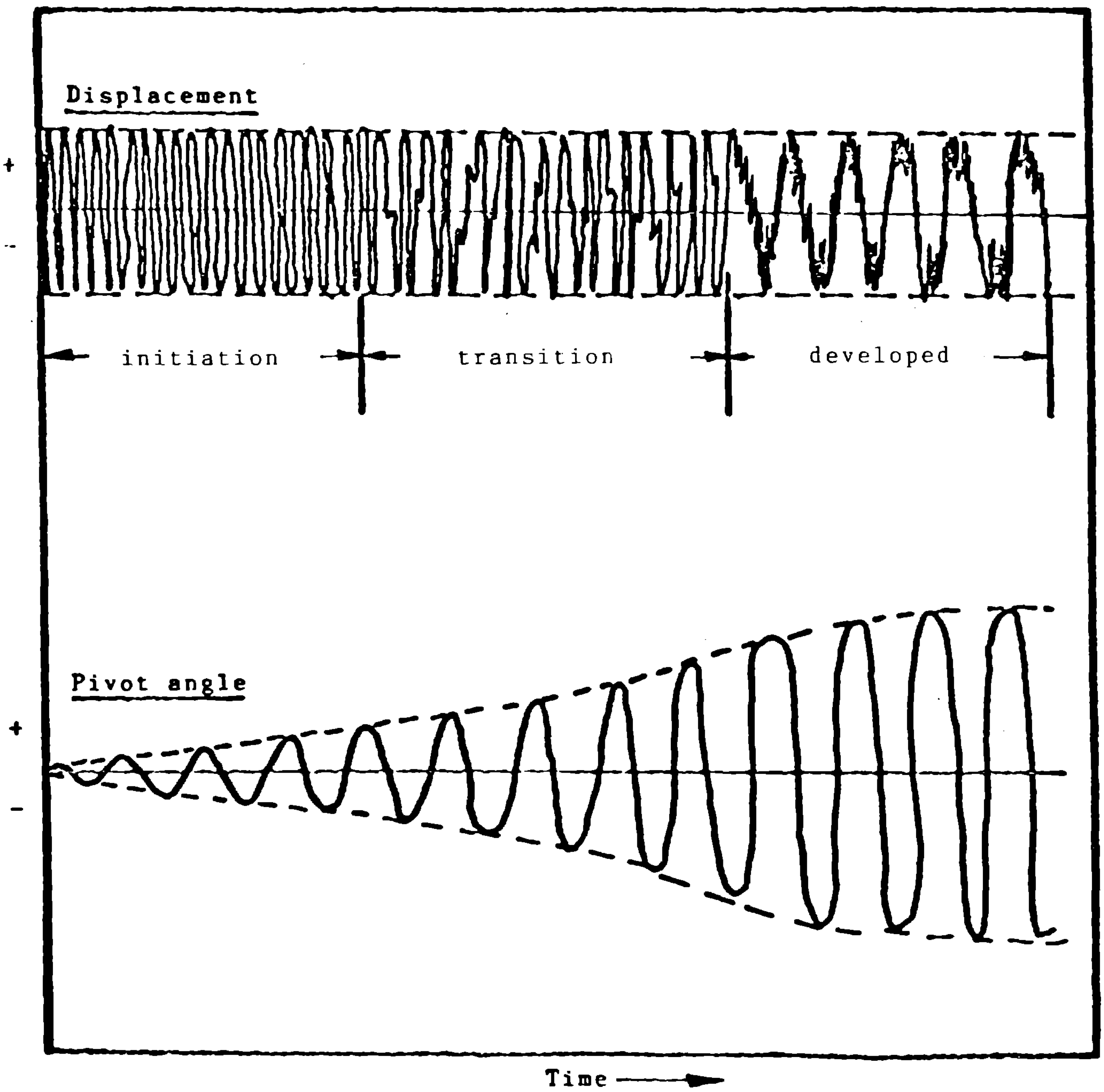


Figure 5 - Depiction of raw data.

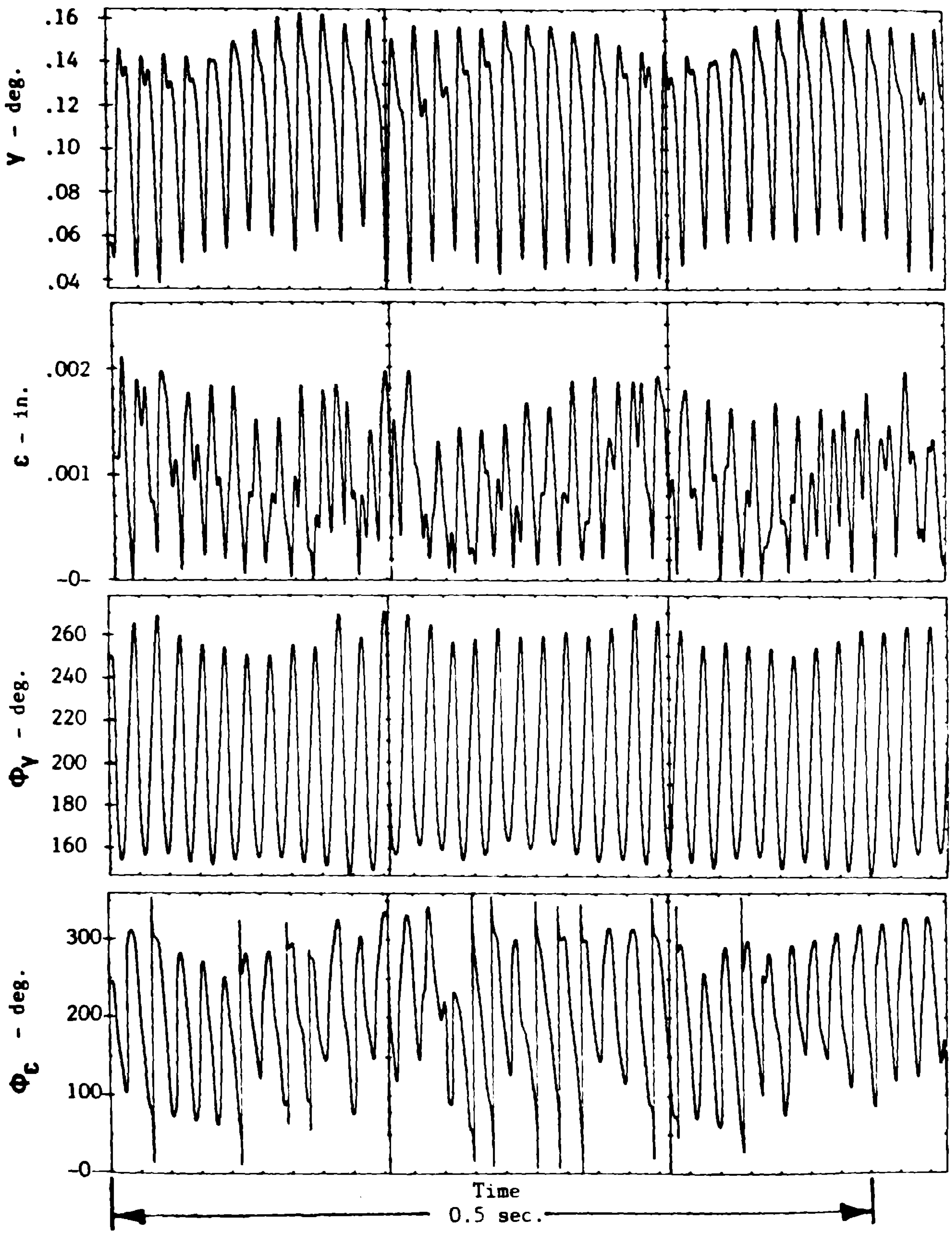


Figure 6 - Developed stage data from round shaft test 4.0.

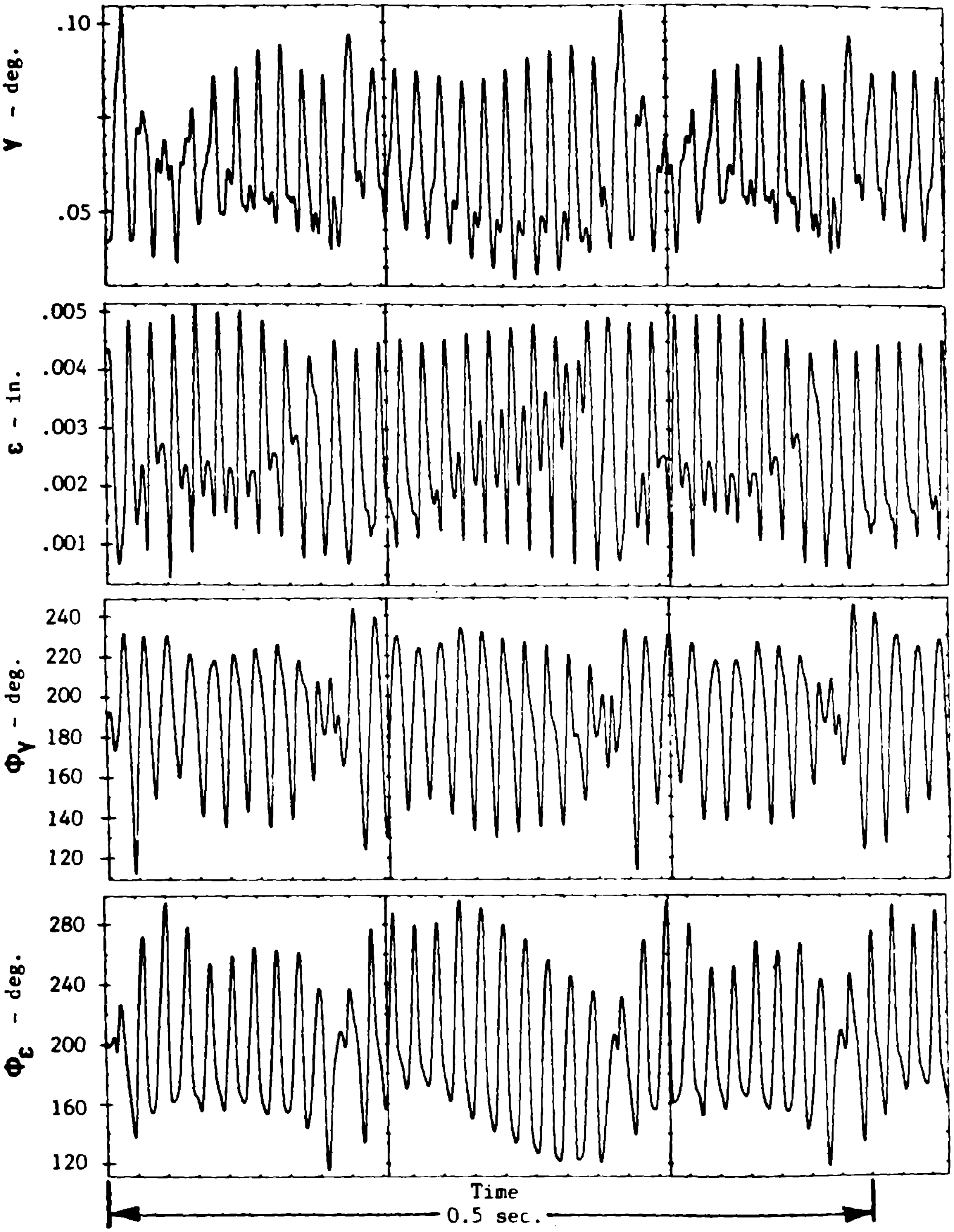


Figure 7 - Developed stage data from octagon shaft test 14.1.